Mobile Robotics: Assignment 1 Report

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1 Epipolar Lines and Epipoles

1.1 Finding Epipolar Lines

We are given F such that $p_2^T F p_1 = 0$. For a given set of n points in the first image, we need to find the epipolar lines for each of these points in the second image. For each given point $\begin{bmatrix} u_1 & v_1 & 1 \end{bmatrix}^T$, we get the epipolar line in the second image $xa + by + c = 0$ as follows:

1. Compute $M_{3\text{x}1} = F_{3\text{x}3} \times \begin{bmatrix} u_1 & v_1 & 1 \end{bmatrix}^T$.
2. The epipolar line is $M_1 x + M_2 y + M_3 = 0$.

For computing the epipolar line of the points of the second image on the first image, do the following:

1. Compute $M_{3\text{x}1} = \begin{bmatrix} u_1 & v_1 & 1 \end{bmatrix} \times F_{3\text{x}3}$.
2. The epipolar line is $M_1 x + M_2 y + M_3 = 0$.

Figure 1 shows the detected epipolar lines.

Figure 1: Epipolar lines on image 1 and 2 respectively.

1.2 Finding Epipoles

For the epipole on the first image (e_1), we know that $p_2^T F p_1 = 0$ for all p_2. So,

$$\begin{aligned} & p_2^T F p_1 = 0 \text{ (for all } p_2) \\ \implies \quad & F p_1 = \mathbf{0} \\ \implies \quad & p_1 = \text{right nullspace of } F \end{aligned}$$

We compute the nullspace of F by finding the point of intersection of the following three lines: find x, y such that $F_1 \begin{bmatrix} x & y & 1 \end{bmatrix}^T = F_2 \begin{bmatrix} x & y & 1 \end{bmatrix}^T = F_3 \begin{bmatrix} x & y & 1 \end{bmatrix}^T$.

Similarly for the epipole on the second image (e_2), the epipole is given by the left nullspace of F: find x, y such that $\begin{bmatrix} x & y & 1 \end{bmatrix} F_{:,1} = \begin{bmatrix} x & y & 1 \end{bmatrix} F_{:,2} = \begin{bmatrix} x & y & 1 \end{bmatrix} F_{:,3}$.

Figure 2 shows the detected the epipoles of both images. The epipoles are respectively $\begin{bmatrix} -5131.90 & -948.85 \end{bmatrix}$ and $\begin{bmatrix} 2159.16 & 1189.26 \end{bmatrix}$.

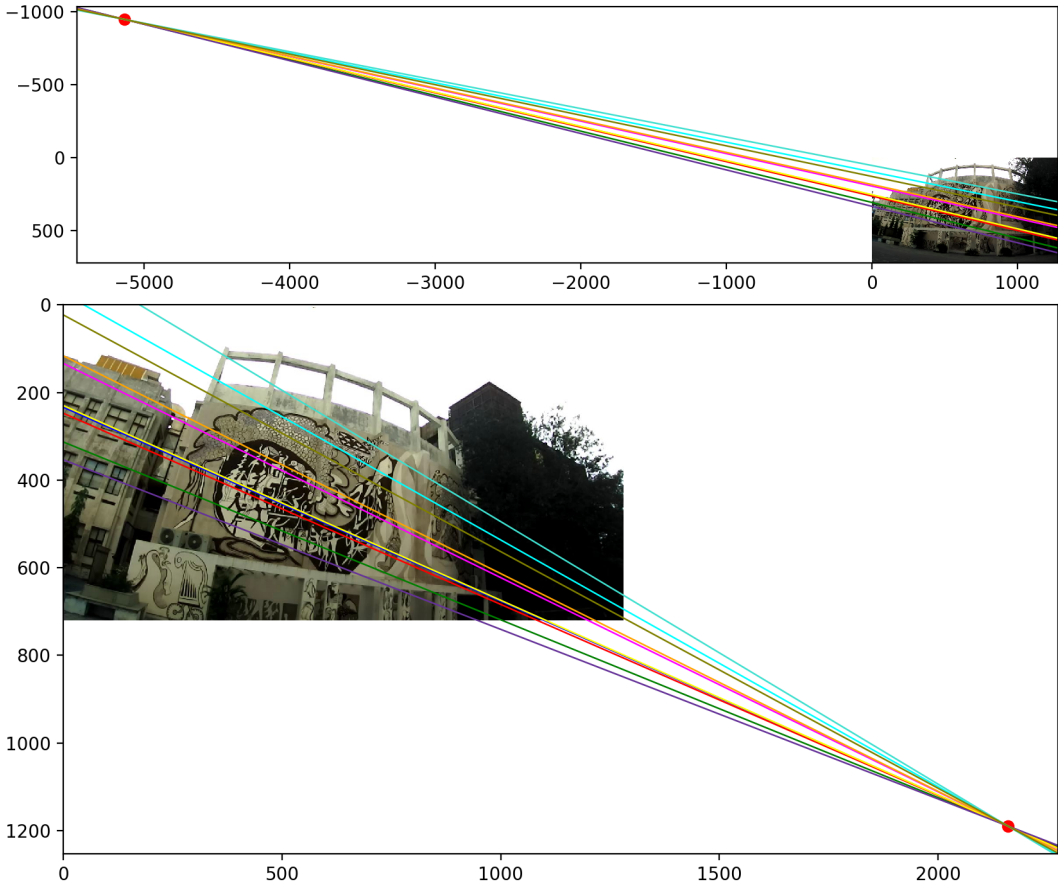

Figure 2: Epipolar lines meeting the epipoles on image 1 and 2 respectively.

2 Feature-based Visual Odometry

2.1 Algorithm

The first goal is to calculate, for two consecutive frames i and $i+1$, the translation and rotation underwent by the camera from i to $i+1$. This is done as follows:

1. The SIFT features are calculated for both images, and matched using a KD-tree-based KNN algorithm.
2. The Fundamental Matrix F is calculated using the 8 point algorithm.
3. The Essential Matrix is calculated as $E = K^T F K$.
4. R and an initial estimate for t is computed using `cv2.recoverPose()`.
5. t is multiplied with the scale — which is computed as the $\ell 2$ norm of the ground truth translation vector of the $(i+1)^{\text{th}}$ frame.
6. We obtain the combined homogeneous matrix of the form $M_{i+1} = \begin{bmatrix} R & t \end{bmatrix}$.

The final output file contains each of these M_i matrices.

2.1.1 Alternate Ways to Compute Scale

Taking the scale from the ground truth file is essentially cheating. It could instead be taken from the speedometer from the vehicle(since the camera has a fixed frame rate, we can estimate the distance).

2.2 Results and Performance

The result on the first sequence is extremely accurate with the maximum erorr going to only 3m. The second sequence(KITTI-6) sees a slightly higher error partially because the sequence is longer(the error builds up over time) and because it has more turns. The final sequence(KITTI-7) illustrates all the issues with the feature based visual odometry. When a vehicle passes by the camera, the feature based visual odometry assumes the egomotion is in the opposite direction. This happens multiple times in the sequence. This in addition to it a long sequence with a lot of turns severely affects the quality of odometry. Figures 3 to 5 show the performance of the odometry calculations compared to the ground truth on some KITTI sequences.

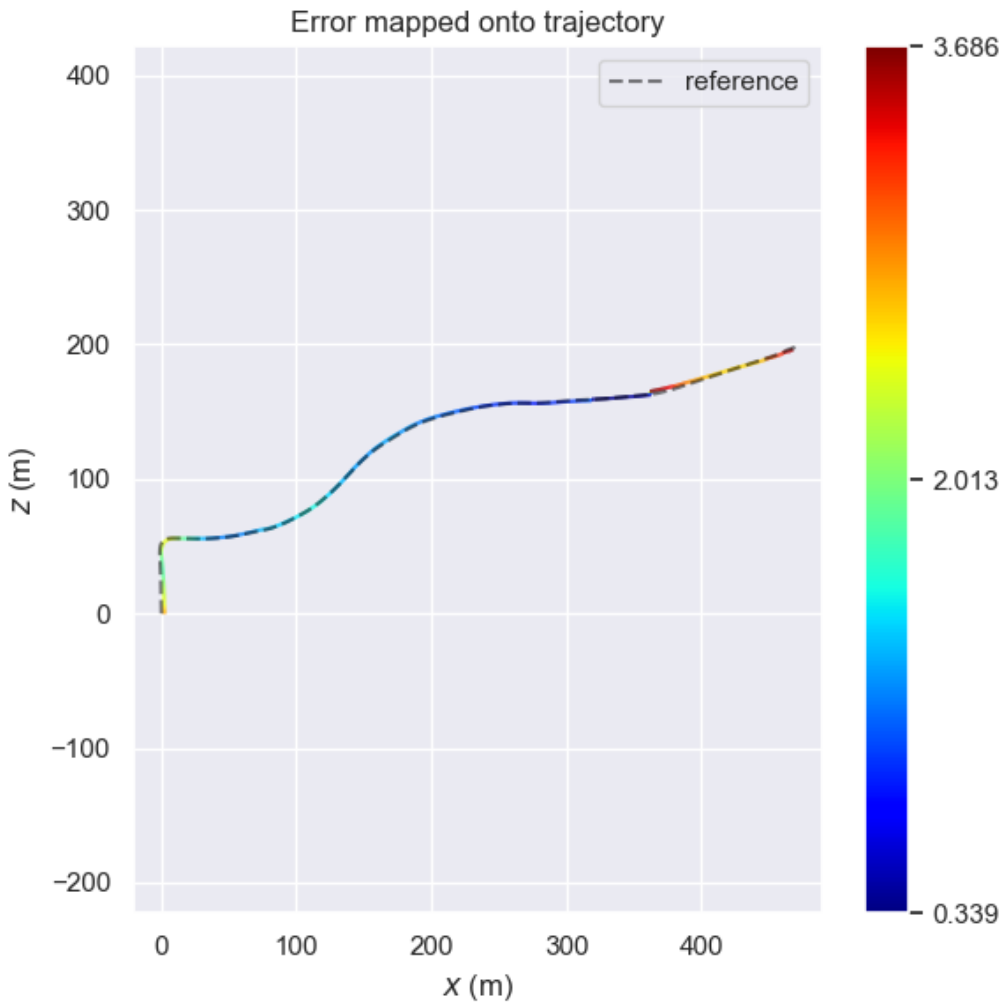

Figure 3: Results on Sequence 1

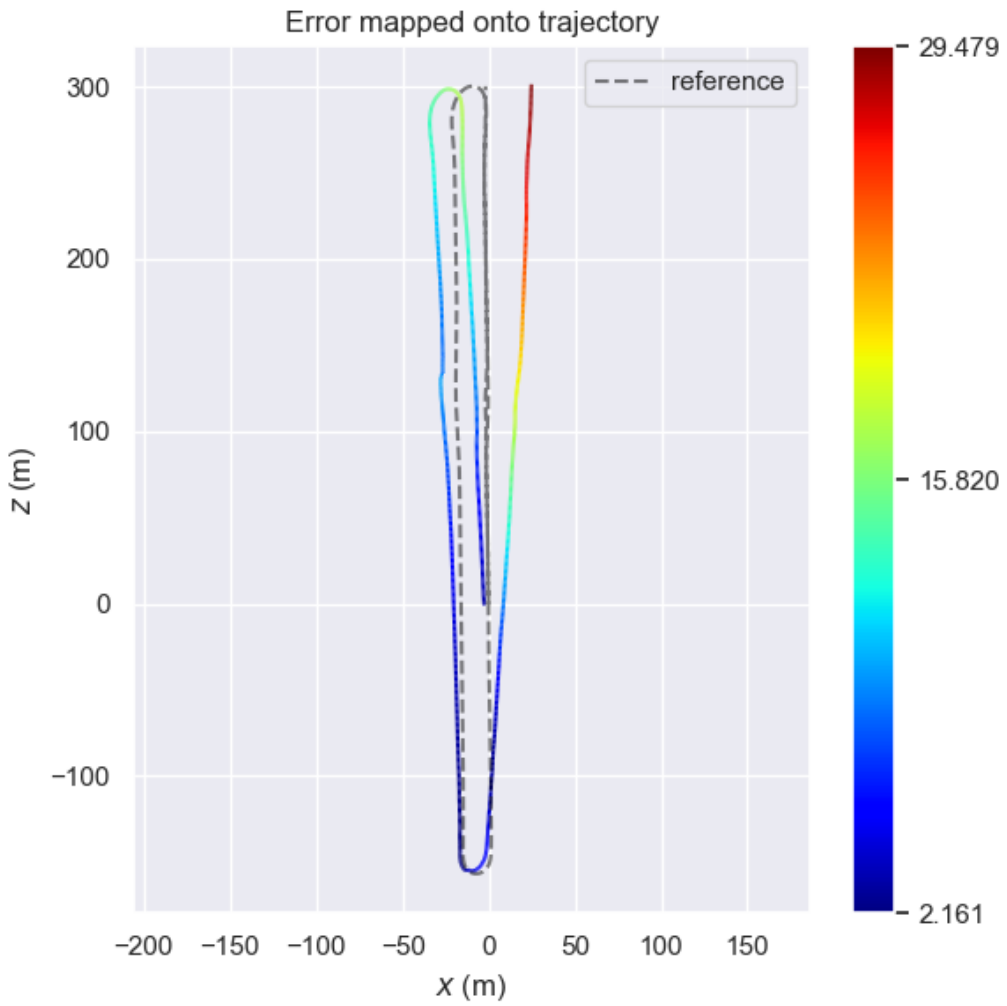

Figure 4: Results on Sequence 6

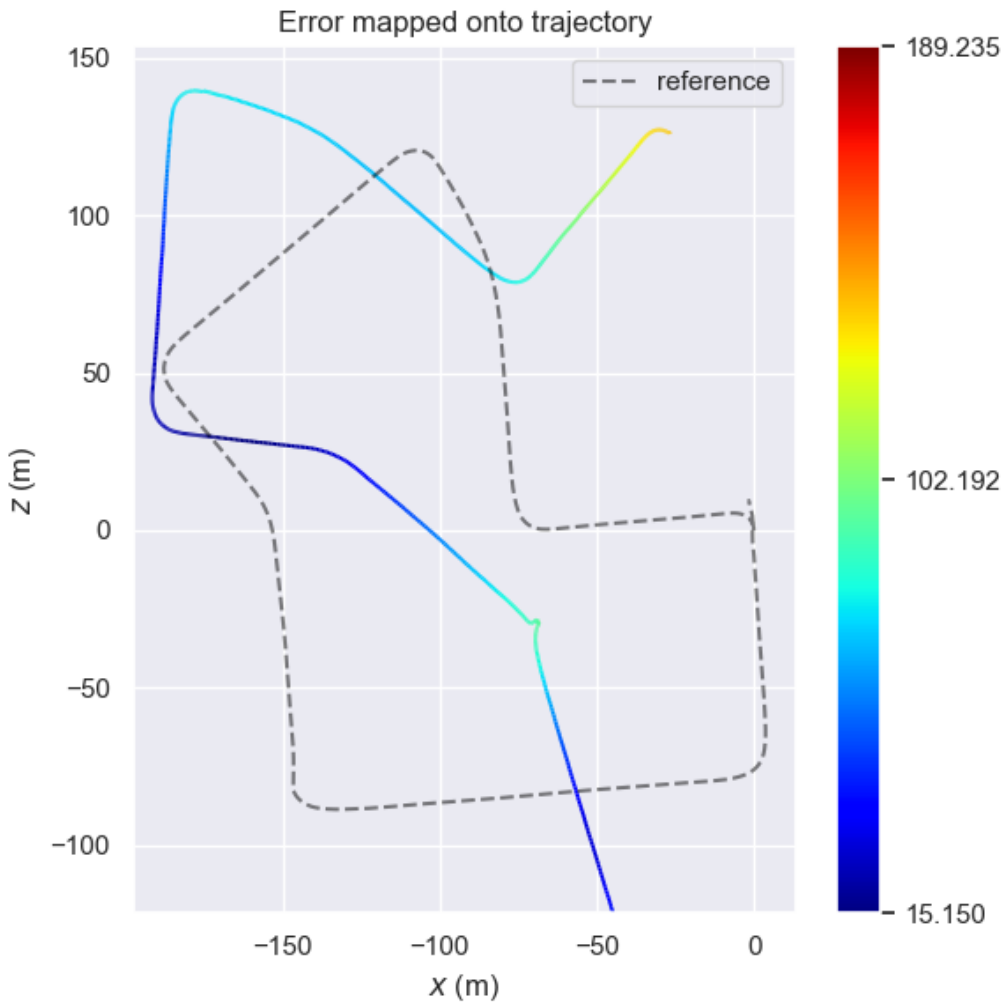

Figure 5: Results on Sequence 7